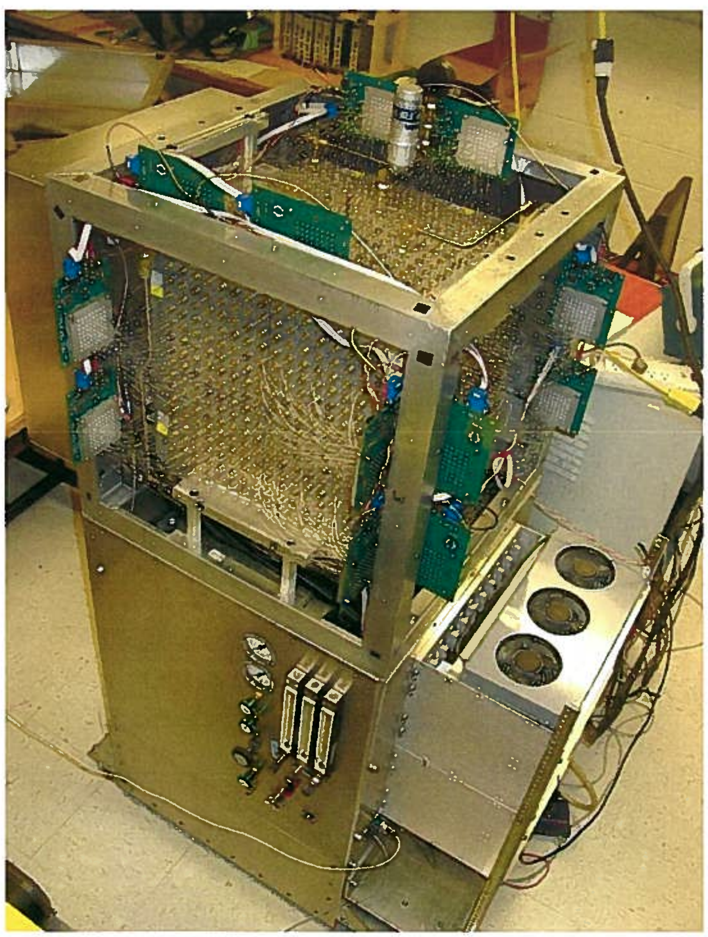
**Fermilab** Directorate

# MEMORANDUM OF UNDERSTANDING
# FOR THE 2011 NEUTRINO PROGRAM

**T-1014**

**IU SciBath-768 Detector**

August 24, 2011



# TABLE OF CONTENTS

## INTRODUCTION

This is a memorandum of understanding between the Fermi National Accelerator Laboratory (Fermilab) and the experimenters of Department of Physics and Center for Exploration of Energy and Matter, Indiana University, who have committed to participate in beam tests to be carried out during the 2011 Fermilab Neutrino program.

The memorandum is intended primarily for the purpose of recording expectations for budget estimates and work allocations for Fermilab, the funding agencies and the participating institutions. It reflects an arrangement that currently is satisfactory to the parties; however, it is recognized and anticipated that changing circumstances of the evolving research program will necessitate revisions. The parties agree to modify this memorandum to reflect such required adjustments. Actual contractual obligations will be set forth in separate documents.

*Description of Detector and Tests:*

The experimenters propose to test a novel prototype "SciBath-768" detector in the MINOS Underground Areas for two beam-months in Fall 2011. There are two major goals for this proposed test run:

1. To observe charged-current neutrino interactions in order to demonstrate vertex reconstruction in the detector. The observation of neutrino interactions in the detector will provide a quantitative demonstration of the detector performance and allow assessment of prospects for future applications of the detector technique.

2. To measure the cosmic-ray induced "fast" (1-100 MeV) neutron flux with $\approx$ 100 m overburden. This flux measurement will constrain backgrounds for underground experiments in general, as well as provide data that can be directly used by the COUPP experiment which ran at the same location.

The MINOS Underground Area is unique in that it allows for both of these measurements simultaneously. For this test run, the experimenters are requesting: space in the Minos Underground Areas for a several-month run; limited technical support for experimental setup; access to power, internet, and accelerator signals; and a small office space from which to run the experiment on the surface.

*Background and Motivation:*

The original motivation for the SciBath detector was the FINeSSE experiment [1], proposed at Fermilab, which had the goal of precisely reconstructing neutrino-nucleon neutral current scattering events ($\nu N \rightarrow \nu N$) in order to extract information on the strange quark contribution to the nucleon spin. This is a challenging measurement as the event signature is a single short proton track within a large detector. The experimenters aim to show that the SciBath technology is well-suited for this application.

A 30-channel "proof-of-principle" device was built and tested at the Indiana University Cyclotron Facility with 200 MeV protons and cosmic-ray muons [2]. Those initial tests showed the promise of the method and allowed for some design tuning. The "Scibath-768" prototype was then built which is now being proposed to bring to Fermilab for neutrino and neutron tests. The device is currently being commissioned at Indiana University.

The goals for running the Scibath-768 detector in the MINOS Underground Areas at Fermilab are twofold. The experiment aims to both demonstrate neutrino event reconstruction and to measure the cosmic induced "fast" neutron flux at a depth of 100 m.

A several-month (1E20 POT) run in the MINOS Underground Areas near the current COUPP apparatus (≈5 mrad off-axis) will provide, depending on the particular NuMI beam configuration at that time, 200 to 12k charged-current neutrino scattering events in a 70 kg liquid scintillator volume. The highest-rate configuration (ν, medium energy) would be the most desirable as it would allow for a physics measurement via a detailed examination of the vertex structure in charged-current quasi-elastic (CCQE) interactions and comparison with models of nuclear recoil. However, the lower-rate configuration would still allow for a demonstration of neutrino event reconstruction, an important milestone for this prototype detector.

The second goal for this proposed test run is to measure the underground flux and energy distribution of fast (1-100 MeV) neutrons.

This spectrum is poorly known, depends on many factors, and is important for low-background underground experiments such as dark matter searches [4]. Since it has a large active volume of liquid scintillator, the SciBath-768 detector should be a good detector of these fast neutrons. Simulations of the detector predict ≈ 30% efficiency and ≈ 30% energy resolution for 10 MeV neutrons with a stopping neutron tag imposed via the delayed 2.2 MeV n-capture photon. The experimenters estimate a rate of detected cosmic-ray induced neutrons of ≈ 16 per day at the MINOS Underground Areas depth [4] which will produce a sizable event sample in a 2-month run. This run will be an important first step in the collaboration's staged program of underground neutron measurements that may continue at deeper locations.

The results will be of interest to underground experiments in general, as it provides a calibration point for underground neutron rates. More specifically, this proposed work will provide a cross check of estimated neutron rates for the COUPP dark matter detector that ran at the same location.

# I. PERSONNEL AND INSTITUTIONS:

Spokespersons and Physicist in charge of Beam Tests: Rex Tayloe

Fermilab liaison: Aria Soha

The group members at present are:

| | Institution | Collaborator | Rank/Position | Other Commitments |
|---|---|---|---|---|
| | | R. Cooper | Postdoc | |
| | | L. Garrison | Graduate student | |
| 1.1 | Indiana University | T. Mikev | Undergraduate | |
| | | L. Rebenitsch | Graduate student | |
| | | Rex Tayloe | Assoc. Prof | MiniBooNE, SciNOvA |

## II. EXPERIMENTAL AREA, BEAMS AND SCHEDULE CONSIDERATIONS:

### 2.1 LOCATION

2.1.1 The apparatus for the beam test(s) will be located in the MINOS Underground Area and requires floor space of minimum dimension 2.8 × 3.3 m$^2$ in a location intercepting the neutrino beam within ~5mrad of the nominal beam axis. The area very near the location of the past COUPP tests would be quite suitable. The experimental equipment does not need to be adjacent to the MINOS or MINERvA detectors and no event-event correlation with these experiments is desired. The orientation of the detector with respect to the neutrino beam direction is not important. A plan view of the proposed layout and required space in the underground area is shown in Appendix I. It may be possible to reconfigure the layout of the specific components to take advantage of available space within the MINOS hall.

2.1.2 The experimenters request a desk in an office on site at Fermilab from which to run the experiment and monitor the detector. The experimenters will, after an initial setup/debug period, run the experiment from the surface.

### 2.2 BEAM

#### 2.2.1 BEAM TYPES AND INTENSITIES

Particles: neutrinos or antineutrinos
Intensity: ~5mrad flux from either of neutrino/antineutrino medium- or low-energy NUMI configurations.
Total integrated flux: The experimenters request running time to collect, at minimum, 200 neutrino or antineutrino events in the volume of detector. In the lowest rate configuration (antineutrino, low-energy) this will require 1E20POT. For other configurations, less flux is required.

#### 2.2.2 BEAM SHARING

The experiment will run parasitically to the MINOS and MINERvA experiments currently using the neutrino beam.

#### 2.2.3 RUNNING TIME

One of the goals of the experiment is a (cosmic-ray) neutron flux measurement; therefore, a fixed run time underground is required. That minimum time is two months in order to collect sufficient number of neutrons.

In the lowest rate configuration of the neutrino beam, a full 1E20POT is required. So the experiment requests a run duration of 1 month for setup and debugging in the experimental area along with up to 3 beam-on months depending on neutrino beam configuration. It is acknowledged that limitations in beam delivery may require more calendar time to obtain the desired total integrated neutrino flux.

## 2.3 Experimental Conditions

### 2.3.1 Area Infrastructure and Electronics Needs

Location of the experiment, underground, is depicted in Appendix I.

The experiment will need:

- A beam-on-target trigger signal to insert into the data stream (with possible technical support for setup).
- Access to an internet connection to surface with minimum 100Mb/s rate
- Access to two 120V/20A electrical outlets. Total power estimated to be not more than 2kW.
- Technical support to assist in moving the experimental equipment into and out of the MINOS Underground Area.

The experiment acknowledges that due to the nature of the underground environment, ground water seeps from the ceiling and walls and pools on the floor, and will take measures to protect their equipment as they see fit, while abiding by fire hazard codes.

### 2.3.2 Description of Detector

The active volume of the SciBath-768 detector consists of 768 1.5 mm diameter ultraviolet-to-blue wavelength-shifting (WLS) fibers immersed in liquid scintillator. There are 256 fibers aligned along each of the 3 axes in a rectangular coordinate system and arranged in a 16 x 16 grid with a spacing of 2.5 cm. The fibers penetrate the 0.5 inch thick aluminum sides of a (45 cm) cube. One end of the WLS fiber is glued into a brass plug and screwed into the box wall. The other end is glued into a stainless steel piston which is free to slide a small distance within a double O-ring system that contains the liquid. The detector is held at a slight overpressure (1 psi) in order to maintain a slight tension on the fibers. Figure 1 shows the (45 cm)$^3$ detector cube with the fiber arrangement and the cover figure shows the cube in the support frame.

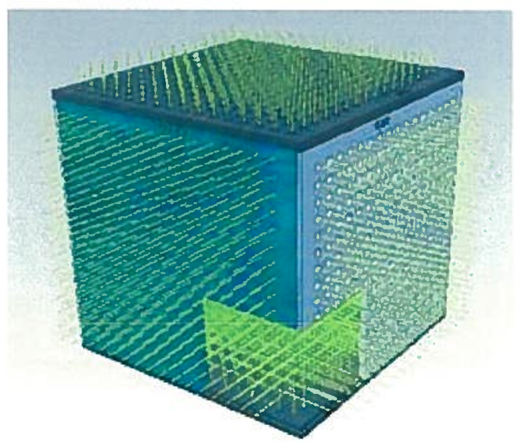


**Figure 1: Schematic view of the SciBath-768 (45 cm)$^3$ detector cube.**

The WLS fibers are mated at one end to clear fibers immediately outside of the aluminum detector walls. These ≈1m long clear fibers are bundled into groups of 64 and routed to VME crates attached to the support structure of the detector. Each bundle terminates in a 64-fiber plastic "cookie" mounted on a custom-built backplane in the VME crate. Hamamatsu 64-anode photomultipliers (MAPMT) attached to the readout cards mate with the fiber cookies so that the fibers align precisely with the 1.7 mm pixels of the MAPMTs. The other end of the WLS fiber is mated to a pulsed LED system that will provide a calibration source for the detector.

The "integrated readout module" (IRM) readout cards combine the readout function with mechanical support for an attached MAPMT. The IRM cards are housed in a VME crate; however the crate is a simple shell with no power supply or parallel readout bus. The power supply is housed in a separate crate and readout is accomplished via ethernet. The rear "backplane" area of the crate accepts the optical fiber bundles. The IRM boards were custom-built at IU and consist of 20 MHz flash ADCs, FPGAs, and an embedded microcontroller which allows on-board data processing and data transfer via ethernet.

The liquid scintillator consists of mineral oil, 11% psuedocumene, and 1.5 g/l PPO resulting in a peak emission wavelength of 370 nm. An additional wavelength shifter (such as bis-MSB), commonly added to liquid scintillator to increase attenuation length, is not necessary for the operation of this detector. The (45 cm)$^3$ cube, when filled, contains 82 liters of scintillator. A nitrogen gas ($N_2$) system is used to displace oxygen and water within the scintillator and to provide the slight (1 psi) overpressure in the detector cube. A reservoir tank with capacity of 104 liters is utilized to store the liquid for transport, to provide a buffer volume for $N_2$ bubbling, and to allow the detector cube to be completely drained as needed. The entire system is protected from pressures over 5psi or vacuum by two protection valves in the $N_2$ system. These will also protect the cube and overflow tank. The liquid scintillator and $N_2$ plumbing arrangement (including the over/under pressure protection valves) is shown schematically in Fig. 2.

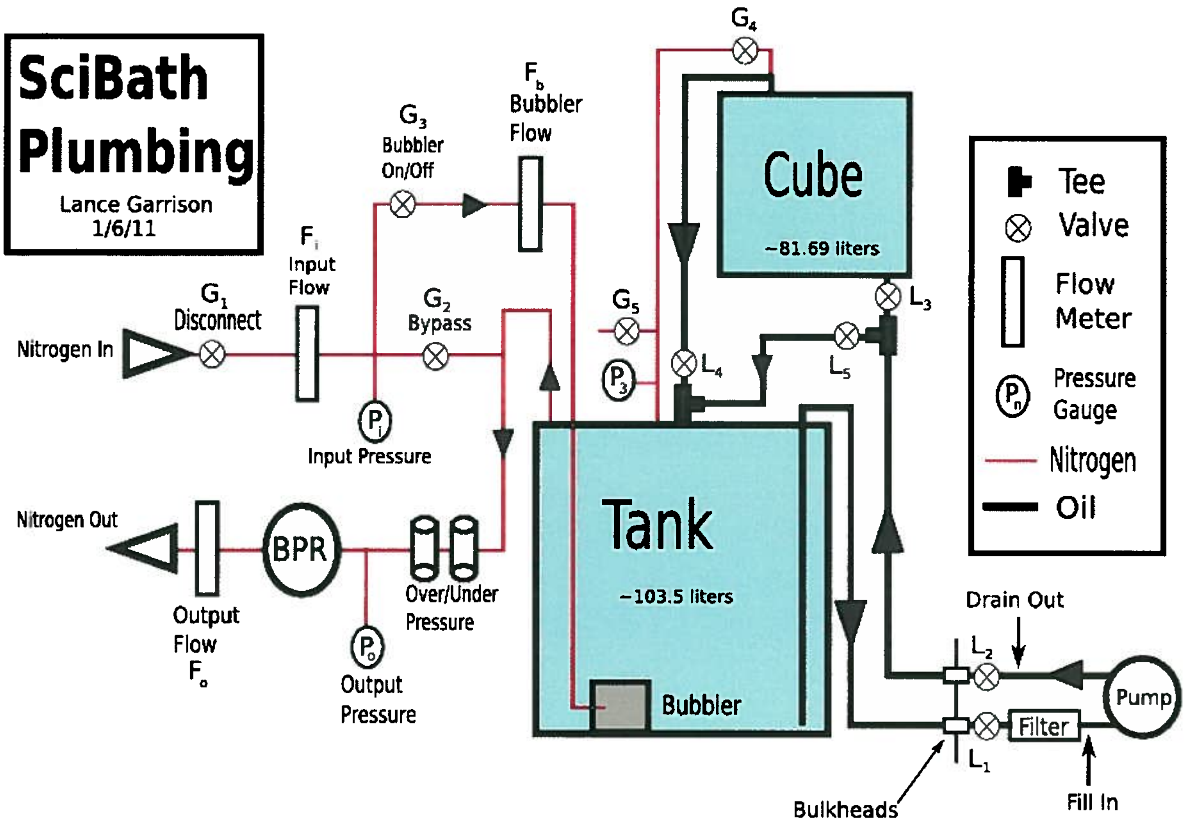



**Figure 2: SciBath-768 liquid scintillator oil and $N_2$ plumbing schematic.**

The (45 cm)$^3$ cube containing the active detector volume and WLS fibers is installed at the top of a custom-built 2 m tall aluminum frame which is mounted on heavy duty casters as shown in the cover photo. Also installed within the aluminum structure is the plumbing system (including the liquid scintillator reservoir tank), the LED calibration system, PMTs and readout cards. The bottom of the detector structure is liquid-tight and functions as a secondary scintillator containment volume in case of any leaks. The entire detector frame will sit in a tertiary container resulting in a three-level containment system to guard against liquid scintillator leaks.

External connections to the detector structure are few so as to allow the detector to be easily moved. These connections consist of 40V and 1000V DC power to the readout/PMT system, 120V AC power for assorted power supplies, several NIM format trigger signals, ethernet, and $N_2$ gas. A half-height 19in rack is used to house the supporting equipment. This rack will be located next to the detector frame and is completely disconnected for transport. A proposed layout of these racks and equipment is shown in Appendix I.

## 2.4 Schedule

The Experiment proposes to run the SciBath-768 detector at Fermilab in the MINOS Underground Area for 2-3 beam-on months in Fall 2011. However, if the beam is configured for low-energy antineutrinos a full 1E20POT will be required. This may take 3-4 months to obtain. In addition, the experimenters anticipate a 1-month setup period before running, and would like to start the setup in September 2011. If 1E20POT can not be delivered before the Fermilab shutdown anticipated in spring 2012, the experimenters acknowledge that the apparatus will have to be removed for the duration of the shutdown and beam after the shutdown will need to be renegotiated.

## III. RESPONSIBILITIES BY INSTITUTION – NON FERMILAB

### 3.1 INDIANA UNIVERSITY:

- IU SciBath detector including the following existing hardware components:
    - liquid scintillator
    - optical fibers
    - containment vessels
    - photomultiplier tubes
    - data acquisition hardware
    - computers
    - local network equipment
    - monitoring computer

Total existing items [$250k]

## IV. Responsibilities by Institution – Fermilab

### 4.1 Fermilab Accelerator Division:

4.1.1 Use of NuMI beam as outlined in Section II.

4.1.2 The beam line elements will be under the control of the AD Operations Department Main Control Room (MCR). [4.0 person-weeks]

4.1.3 Maintenance of all existing standard beam line elements instrumentation, controls, clock distribution, and power supplies.

4.1.4 A beam-on-target trigger signal to insert into the experiment data stream

### 4.2 Fermilab Particle Physics Division:

4.2.1 The test-beam efforts in this MOU will make use of NuMI beam as outlined in Section II. The Fermilab Particle Physics Division will be responsible for coordinating overall activities in the MINOS Underground Area. [4.0 person-weeks]

4.2.2 Technical support to assist in moving the experimental equipment into and out of the MINOS Underground Area. [0.5 person-weeks]

4.2.3 A desk in a visitor area on site, at Fermilab from which to run the experiment and monitor the detector.

4.2.4 Access to two 120V, 20A electrical outlets with total power estimated to be less than 2kW

### 4.3 Fermilab Computing Division

4.3.1 Access to an internet connection to surface with minimum 100Mb/s rate.

### 4.4 Fermilab ES&H Section

4.4.1 Assistance with safety reviews.

4.4.2 Provide necessary training for experimenters.

## V. SUMMARY OF COSTS

| Source of Funds [$K] | Materials & Services | Labor (person-weeks) |
|---|---|---|
| Particle Physics Division | 0.0 | 4.5 |
| Accelerator Division | 0 | 0 |
| Computing Division | 0 | 0 |
| | | |
| Totals Fermilab | $0.0K | 4.5 |
| Totals Non-Fermilab | $250K | 40 |

## VI. Special Considerations

6.1 The responsibilities of the Spokesperson and the procedures to be followed by experimenters are found in the Fermilab publication "Procedures for Researchers": (http://www.fnal.gov/directorate/PFX/PFX.pdf). The Spokesperson agrees to those responsibilities and to ensure that the experimenters all follow the described procedures.

6.2 To carry out the experiment a number of Environmental, Safety and Health (ES&H) reviews are necessary. This includes creating an Operational Readiness Clearance document in conjunction with the standing Particle Physics Division committee. The Spokesperson will follow those procedures in a timely manner, as well as any other requirements put forth by the Division's Safety Officer.

6.3 The Spokesperson will ensure one person is on-call and available by phone at all times whenever the detector is being operated and that this person is knowledgeable about the experiment's hazards.

6.4 All regulations concerning radioactive sources will be followed. No radioactive sources will be carried onto the site or moved without the approval of the Fermilab ES&H section.

6.5 All items in the Fermilab Policy on Computing will be followed by the experimenters. (http://computing.fnal.gov/cd/policy/cpolicy.pdf).

6.6 The Spokesperson will undertake to ensure no PREP or computing equipment be transferred from the experiment to another use except with the approval of and through the mechanism provided by the Computing Division management. The Spokesperson also undertakes to ensure no modifications of PREP equipment take place without the knowledge and written consent of the Computing Division management.

6.7 The experimenters will be responsible for maintaining both the electronics and the computing hardware supplied by them for the experiment. Fermilab will be responsible for repair and maintenance of the Fermilab-supplied electronics. Any items for which the experiment requests that Fermilab performs maintenance and repair should appear explicitly in this agreement.

*At the completion of the experiment:*

6.8 The Spokesperson is responsible for the return of all PREP equipment, computing equipment and non-PREP data acquisition electronics. If the return is not completed after a period of one year after the end of running the Spokesperson will be required to furnish, in writing, an explanation for any non-return.

6.9 The experimenters agree to remove their experimental equipment as the Laboratory requests them to. They agree to remove it expeditiously and in compliance with all ES&H requirements, including those related to transportation. All the expenses and personnel for the removal will be borne by the experimenters unless removal requires facilities and personnel not able to be supplied by them, such a rigging, crane operation, etc.

6.10 The experimenters will assist the Fermilab Divisions and Sections with the disposition of any articles left in the offices they occupied.

6.11 An experimenter will be available to report on the test beam effort at a Fermilab All Experimenters' Meeting.

## VII. References

[1] L. Bugel et al. [FINeSSE Collaboration], "A Proposal for a near detector experiment on the booster neutrino beamline: FINeSSE: Fermilab intense neutrino scattering scintillator experiment," arXiv:hep-ex/0402007.

[2] R. Tayloe et al., "A large-volume detector capable of charged-particle tracking," Nucl. Instrum. Meth. A 562, 198 (2006).

[3] D. Casper, Nucl. Phys. Proc. Suppl. 112, 161 (2002).

[4] D. Mei and A. Hime, "Muon-Induced Background Study for Underground Laboratories," Phys. Rev. D 73, 053004 (2006) [arXiv:astro-ph/0512125].

**SIGNATURES**

______________________________ / / 2011
Rex Tayloe, Experiment Spokesperson

______________________________ 9 /13/ 2011
Michael Lindgren, Particle Physics Division, Fermilab

______________________________ 9 / 15 / 2011
Roger Dixon, Accelerator Division, Fermilab

______________________________ 9 / 15 / 2011
Peter Cooper, Computing Division, Fermilab

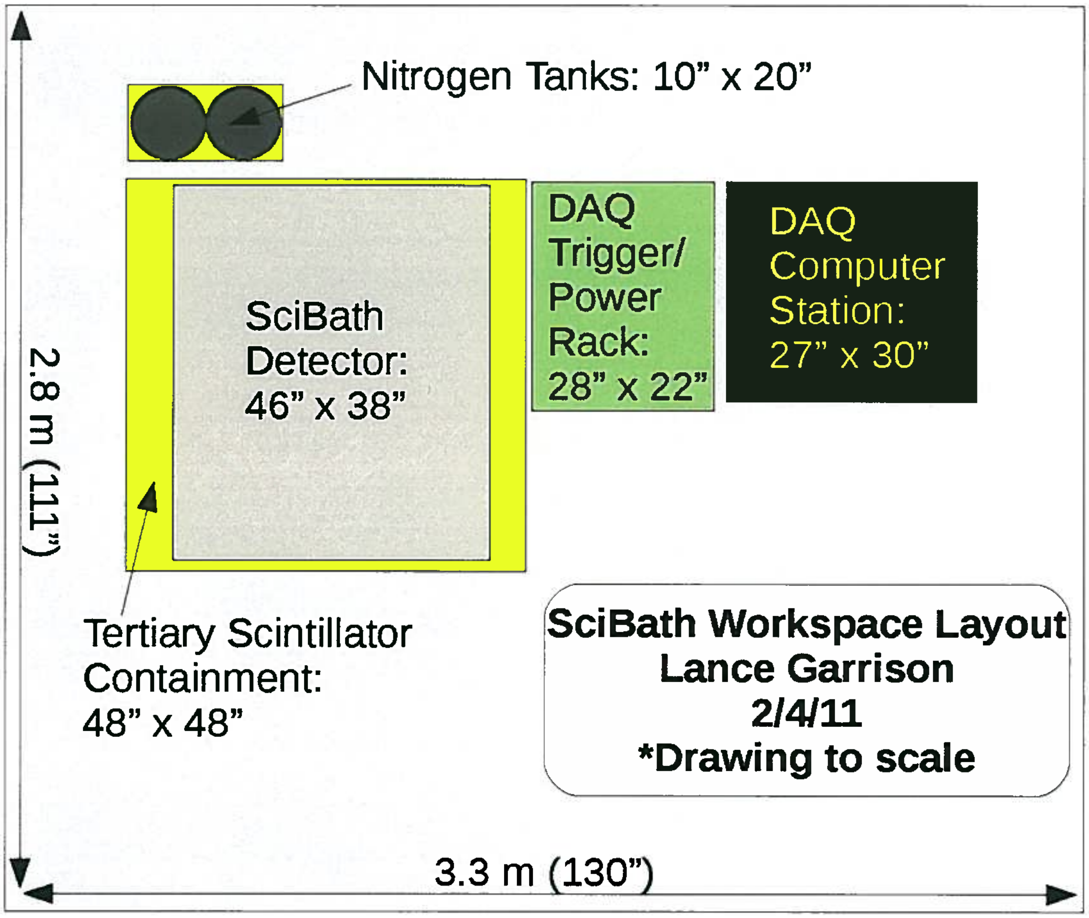
Teri Dykhuis for Nancy Grossman 9/13/2001 ~~/ / 2011~~
Nancy Grossman, ES&H Section, Fermilab

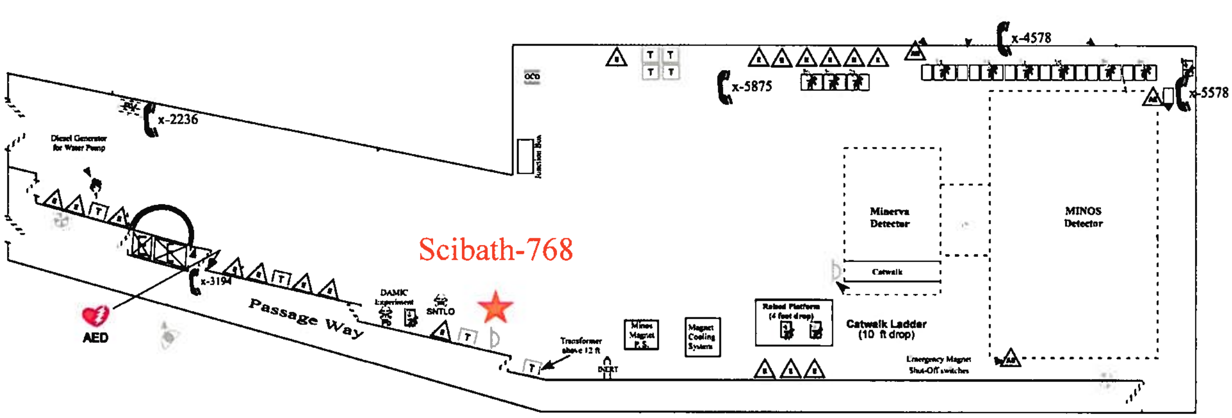
______________________________ 9 /15/2011
Greg Bock, Associate Director for Research, Fermilab

______________________________ 9 /16/2011
Stuart Henderson, Associate Director for Accelerators, Fermilab

## APPENDIX I: AREA LAYOUT

Layout of the proposed Scibath-768 test experiment within the MINOS Underground Area, with dimensions. The estimated total weight of all equipment is ≈ 350 kg (≈700 lbs).



## APPENDIX II: - HAZARD IDENTIFICATION CHECKLIST

Items for which there is anticipated need have been checked. See next page for detailed descriptions of categories.

Notes:

- HV is that for PMT bases (~1kV, 1mA).
- Scintillation oil is mineral oil with 10% pseudocumene.

| **Flammable Gases or Liquids** | | **Other Gas Emissions** | | **Hazardous Chemicals** | | **Other Hazardous /Toxic Materials** |
|---|---|---|---|---|---|---|
| Type: | | Type: | Nitrogen gas | | Cyanide plating materials | List hazardous/toxic materials planned for use in a beam line or an experimental enclosure: |
| Flow rate: | | Flow rate: | <= 1liter/min | | Hydrofluoric Acid | |
| Capacity: | | Capacity: | | | Methane | |
| **Radioactive Sources** | | **Target Materials** | | | photographic developers | |
| | Permanent Installation | | Beryllium (Be) | | PolyChlorinatedBiphenyls | |
| | Temporary Use | | Lithium (Li) | X | Scintillation Oil | |
| Type: | | | Mercury (Hg) | | TEA | |
| Strength: | | | Lead (Pb) | | TMAE | |
| **Lasers** | | | Tungsten (W) | | Other: Activated Water? | |
| | Permanent installation | | Uranium (U) | | | |
| | Temporary installation | | Other: | **Nuclear Materials** | | |
| | Calibration | **Electrical Equipment** | | Name: | | |
| | Alignment | | Cryo/Electrical devices | Weight: | | |
| Type: | | | Capacitor Banks | **Mechanical Structures** | | |
| Wattage: | | X | High Voltage (50V) | | Lifting Devices | |
| Class: | | | Exposed Equipment over 50 V | | Motion Controllers | |
| | | X | Non-commercial/Non-PREP | | Scaffolding/ Elevated Platforms | |
| | | | Modified Commercial/PREP | | Other: | |
| **Vacuum Vessels** | | **Pressure Vessels** | | **Cryogenics** | | |
| Inside Diameter: | | Inside Diameter: | | | Beam line magnets | |
| Operating Pressure: | | Operating Pressure: | | | Analysis magnets | |
| Window Material: | | Window Material: | | | Target | |
| Window Thickness: | | Window Thickness: | | | Bubble chamber | |

## NUCLEAR MATERIALS

### Reportable Elements and Isotopes / Weight Units / Rounding

| Name of Material | MT Code | Reporting Weight Unit Report to Nearest Whole Unit | Element Weight | Isotope Weight | Isotope Weight % |
|---|---|---|---|---|---|
| Depleted Uranium | 10 | Whole Kg | Total U | U-235 | U-235 |
| Enriched Uranium | 20 | Whole Gm | Total U | U-235 | U-235 |
| Plutonium-242[1] | 40 | Whole Gm | Total Pu | Pu-242 | Pu-242 |
| Americium-241[2] | 44 | Whole Gm | Total Am | Am-241 | – |
| Americium-243[2] | 45 | Whole Gm | Total Am | Am-243 | – |
| Curium | 46 | Whole Gm | Total Cm | Cm-246 | – |
| Californium | 48 | Whole Microgram | – | Cf-252 | – |
| Plutonium | 50 | Whole Gm | Total Pu | Pu-239+Pu-241 | Pu-240 |
| Enriched Lithium | 60 | Whole Kg | Total Li | Li-6 | Li-6 |
| Uranium-233 | 70 | Whole Gm | Total U | U-233 | U-232 (ppm) |
| Normal Uranium | 81 | Whole Kg | Total U | – | – |
| Neptunium-237 | 82 | Whole Gm | Total Np | – | – |
| Plutonium-238[3] | 83 | Gm to tenth | Total Pu | Pu-238 | Pu-238 |
| Deuterium[4] | 86 | Kg to tenth | $D_2O$ | $D_2$ | |
| Tritium[5] | 87 | Gm to hundredth | Total H-3 | – | – |
| Thorium | 88 | Whole Kg | Total Th | – | – |
| Uranium in Cascades[6] | 89 | Whole Gm | Total U | U-235 | U-235 |

[1] Report as Pu-242 if the contained Pu-242 is 20 percent or greater of total plutonium by weight; otherwise, report as Pu 239-241.

[2] Americium and Neptunium-237 contained in plutonium as part of the natural in-growth process are not required to be accounted for or reported until separated from the plutonium.

[3] Report as Pu-238 if the contained Pu-238 is 10 percent or greater of total plutonium by weight; otherwise, report as plutonium Pu 239-241.

[4] For deuterium in the form of heavy water, both the element and isotope weight fields should be used; otherwise, report isotope weight only.

[5] Tritium contained in water (H2O or D2O) used as a moderator in a nuclear reactor is not an accountable material.

[6] Uranium in cascades is treated as enriched uranium and should be reported as material type 89.

## OTHER GAS EMISSION

**Greenhouse Gasses** (Need to be tracked and reported to DOE)

- ❑ Carbon Dioxide, including $CO_2$ mixes such as $Ar/CO_2$
- ❑ Methane
- ❑ Nitrous Oxide
- ❑ Sulfur Hexafluoride
- ❑ Hydro fluorocarbons
- ❑ Per fluorocarbons
- ❑ Nitrogen Trifluoride